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Capacity Evaluation of LoS-Optimised and Standard MIMO Antenna Arrays at 5.2 GHz

Ioannis Sarris*, and Andrew R. Nix†

Abstract— In this paper, the channel capacity of MIMO communication systems is evaluated from measurements in a home environment at 5.2 GHz. The capacity performance of a novel Line-of-Sight (LoS)-optimised antenna array architecture is investigated and compared to that of standard MIMO antenna arrays with one-wavelength inter-element spacing. Several transmit/receive locations are taken into account including LoS, non-LoS and obstructed-LoS areas. The results reveal that the proposed architecture can offer a significant capacity increase (more than 50%) in LoS environments compared to standard MIMO arrays. On the other hand, in non-LoS scenarios the performance of the proposed array is similar to the standard architecture.

I. INTRODUCTION

An area that is recently attracting a growing interest is that of ultra-broadband wireless networks in the home environment. This interest is mainly driven by the ever increasing need for higher data rate access to the internet but also by the need of accessing high-definition audio and video content wirelessly. A solution that can provide the required capacity for such applications is that of Multiple-Input Multiple-Output systems, where arrays of multiple antenna elements are employed at the transmitter and the receiver.

One popular MIMO transmission scheme is Spatial Multiplexing (SM) which relies on transmitting independent data streams from each transmit antenna. Under specific propagation conditions, the data-rate in a MIMO system employing this scheme increases linearly with the minimum number of transmit and receive antenna elements **Error! Reference source not found.** This enhancement is achieved by the utilisation of a number of spatial sub-channels between each set of transmit and receive elements. One example where this increase can occur is a rich-scattering environment, where a large number of independent communications paths exists between the transmit and receive antenna elements.

When a Line-of-Sight (LoS) signal is present however, the performance of MIMO systems is limited due to the high correlation between the received signals **Error! Reference source not found.**, [1]. This correlation is experienced as very small variations on the spatial signature of the received signals and thus limits the number of independent communication sub-channels. Since the probability of a LoS signal in a home environment is high, a solution to the problem of reduced LoS performance is highly desirable.

In this paper, work performed under the framework of the IST Audio-visual STReaming pLATFORM for domestic Leisure and Security (ASTRALS) project is presented. The authors investigate the channel capacity of MIMO systems with LoS-optimised and standard antenna array architectures.

II. FULL-RANK LoS COMMUNICATIONS

As mentioned previously, work in the area of MIMO communications has shown that in LoS conditions excessive correlation is observed due to the linear relationship of the phases of the received signals [1]. Contrary to this observation however, a number of studies have shown that by using specifically designed antenna arrays the orthogonality of the received signals can be preserved [2-7]. Under these conditions a number (equal to the minimum of the number of transmit and receive elements) of parallel sub-channels are effectively created between the transmitting and receiving arrays; thus realizing a full-rank LoS channel response. The channel capacity is then higher than that of the i.i.d. Rayleigh model for rich-scattering environments [5-7].

For the special case of Uniform Linear Arrays (ULAs) at both ends of a MIMO system a simple criterion has been derived that defines an infinite number of array architectures with full-rank LoS responses [5, 7]. This is expressed by the following equation for a system with N_t transmit elements and N_r receive elements:

$$s_1 s_2 \approx \lambda \left(\frac{1}{N_t} + r \right) \frac{D}{\sin \omega \sin \theta}, r \in \mathbf{Z}^+ \quad (1)$$

In the equation above s_1 , s_2 , ω and θ correspond to the geometry of Fig. 1, λ corresponds to the wavelength, D is the distance between the two arrays, and finally \mathbf{Z}^+ corresponds to the set of positive integers.

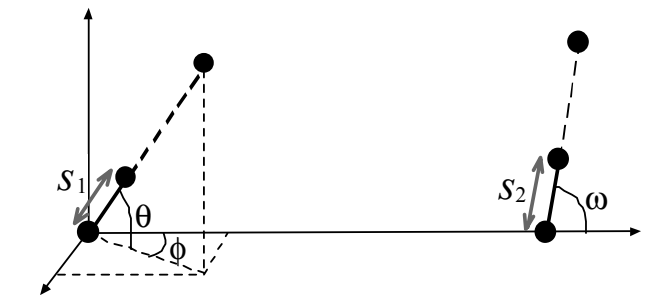


Figure 1 Uniform Linear Array orientations

III. MEASUREMENT PROCEDURE

Previous measurements have verified the capacity gain of LoS-optimised MIMO arrays in pure-LoS (anechoic chamber) and indoor office environments. In this paper, the scenario of

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LoS-optimised structures in a home environment is investigated.

A. Environment

An outline of the environment and the measurement locations is shown in the following figure. The locations can be categorised as LoS (loc. 1-25), non-LoS (loc. 26-31) and obstructed-LoS (loc. 32-36). For this measurement the receive array was placed in parallel to the ground plane (Figure 7).

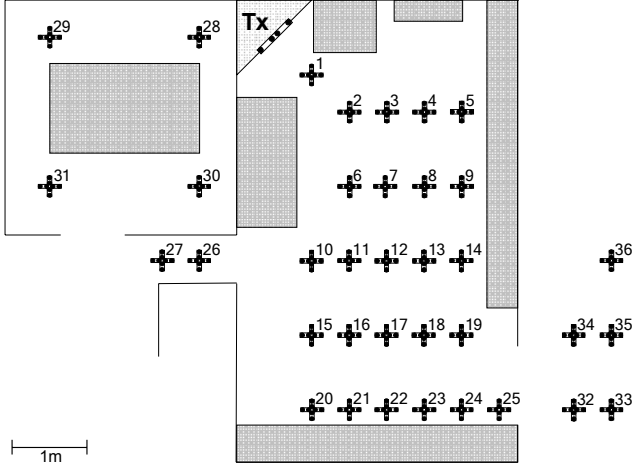


Figure 2 Tx (fixed) and Rx antenna array locations (Rx parallel to ground plane)

An additional measurement was also conducted for the case where the receiver was vertical to the ground plane (Figure 8). The measurement locations for this case are shown in the figure below.

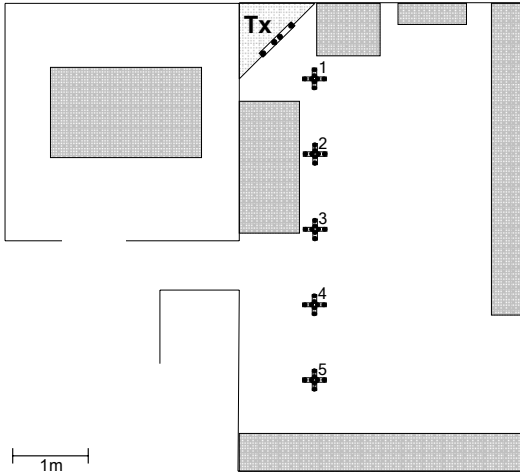


Figure 3 Tx (fixed) and Rx antenna array locations (Rx vertical to ground plane)



Figure 4 Tx and Rx antenna arrays in lounge area

B. Antenna Arrays

During our investigation a 4-element transmit array and an 8-element receive array were employed. However, only 2x2 subsets of the 4x8 system were taken into account in each instance according to the scenario (LoS-optimised or standard system) of interest. The following figure presents the antenna array configurations. Please note that all the antenna elements used in this measurement campaign were identical dual-polarised patch antennas.

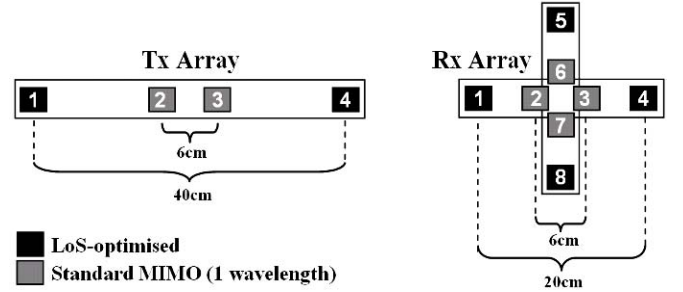


Figure 5 Tx and Rx array structures

In the above arrays, the antenna elements in black colour correspond to the LoS-optimised architecture (where the spacing is calculated from (1)) whereas the antenna elements in grey colour correspond to the standard MIMO architecture with one-wavelength spacing. At the receive array in particular an adaptive selection method is applied in the post-processing stage. In detail, the set of two elements out of the four for each scenario (LoS-optimised or standard) was selected at each location. Therefore, in the LoS-optimised case the receive elements 5 and 8 or 1 and 4 were selected, whereas for the standard case the elements 2 and 3 or 6 and 7 were selected for communication at each instance.



Figure 6 Tx antenna array



Figure 7 Rx antenna array (parallel to ground plane)



Figure 8 Rx antenna array (vertical to ground plane)

C. Measurement Equipment

The measurements were performed using a MEDAV RUSK BRI MIMO vector channel sounder (Figure 9). This employs a periodic multi-tone signal with a bandwidth of 120 MHz,

centred at 5.2 GHz, and with a variable measurement period between $0.8 \mu\text{s}$ and $25.6 \mu\text{s}$. A fast multiplexing system is used to switch the receiver between each of the active elements in turn in order to take a full vector snapshot of the channel. The receiver down-converts the resultant RF signal to an 80 MHz IF which is then sampled at 320 MHz.

This data is then converted to the frequency domain before being stored to a hard disk for subsequent post-processing. Measurement time accuracy is assured through the use of Rubidium referenced blocks at both the transmitter and the receiver, with an optical fibre connection providing synchronisation and absolute phase stability. The start of each measurement campaign is also preceded by a back-to-back system calibration that accounts for any amplitude and phase distortions in the hardware. Further calibration is also conducted on the receive array to compensate for mutual coupling.

For each transmit element in turn, a vector snapshot of the channel is taken at the receiver. In this way, consecutive vector snapshots contain the channel responses of all combinations of the transmit and receive elements. Operating the channel sounder at its fastest repetition rate ($0.8 \mu\text{s}$) allows a full MIMO snapshot of the channel to be recorded well within the coherence time of an indoor channel. More details about the channel sounding equipment can be found in [5].



Figure 9 The RUSK BRI MIMO channel sounder

D. Post-Processing

In all measurements the MIMO channel response matrix was recorded for 1024 time snapshots. In the post-processing stage the channel matrix was normalized so that the effect of the array architectures is studied independently of the path-loss. The normalization was performed using the following equation:

$$E \left\{ \left\| \mathbf{H} \right\|_F^2 \right\} = N_t N_r \quad (2)$$

In the above expression $E \{ \}$ corresponds to the expectation operation and $\left\| \cdot \right\|_F$ represents the Frobenius norm. In

physical terms, this normalization corresponds to a system with perfect power control.

IV. RESULTS AND DISCUSSION

The capacity of the LoS-optimised configuration and the standard system are shown in Figure 10 for the LoS locations as a function of the distance between the two arrays. It is clear that the performance of the LoS-optimised array is significantly higher than that of the standard system with capacity gains of up to 48.8% near the transmitter. It is also interesting to note that the LoS-optimised array achieved higher capacity than the i.i.d. Rayleigh model (11.4 bps/Hz for SNR = 20 dB) in 22 of the 25 locations.

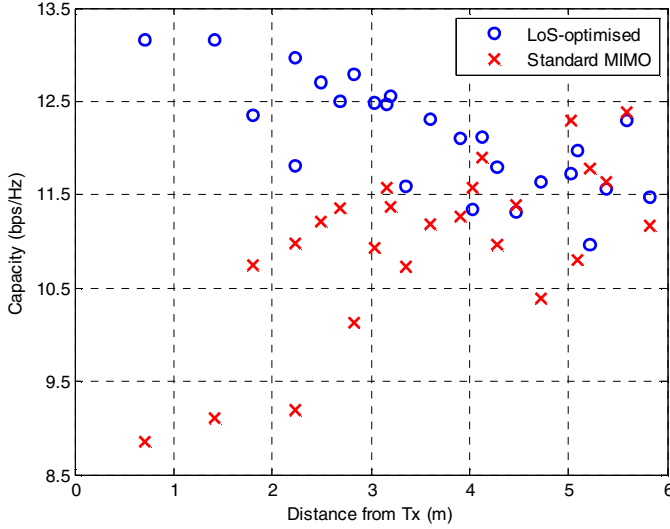


Figure 10 Capacity as a function of distance from the Tx (Rx array parallel to ground plane)

Figure 11 presents the measured capacity for non-LoS locations. It is clear that the capacities from both the LoS-optimised and the standard systems are very similar. This was expected since the signals arriving at both arrays are non-LoS and therefore capacities near the i.i.d. Rayleigh capacity were achieved.

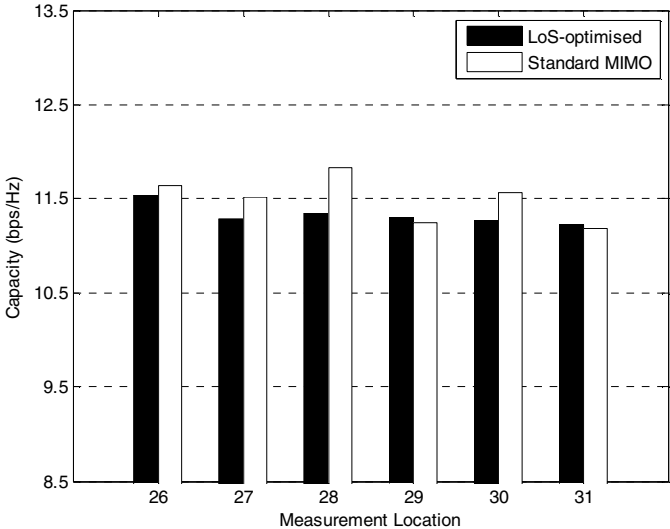


Figure 11 Capacity variation in non-LoS area

Figure 12 presents the capacities in the patio area where the LoS signal was obstructed from the patio door. In this scenario the LoS-optimised array architecture offered a significant gain in capacity compared to the standard MIMO architecture. This can be attributed to the keyhole effect where a single unique path exists between the transmit and receive arrays.

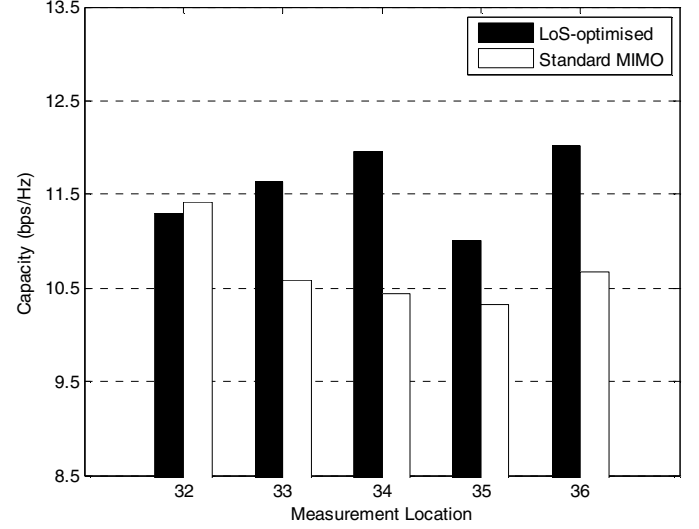


Figure 12 Capacity variation in obstructed-LoS area

Another configuration that was investigated was that of the receive array being in a vertical position to the ground plane. The capacities for this scenario in the LoS area are shown below as a function of the transmitter-to-receiver distance.

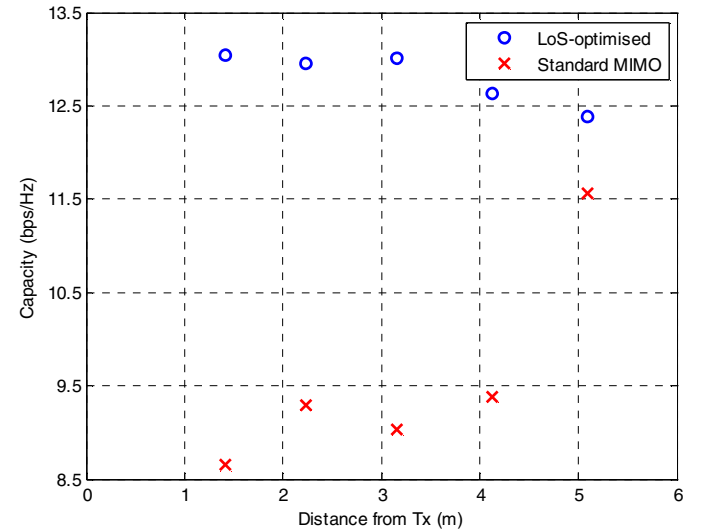


Figure 13 Capacity as a function of distance from the Tx (Rx array vertical to ground plane)

Clearly, the LoS-optimised antenna architecture has provided a significant gain to the capacity compared to a standard array of one-wavelength spacing. In detail, the capacity near the transmit array was found to be 50.7 % higher in the LoS-optimised case.

V. CONCLUSIONS

In this paper the performance of specifically designed LoS-optimised antenna array architectures was investigated. The capacity results from the MIMO measurement campaign reveal the superiority of the proposed array architecture compared with standard antenna arrays of inter-element spacing of one-wavelength. The performance of the proposed and the standard systems are very similar in non-LoS locations whereas the LoS-optimised system outperforms the standard architecture in obstructed-LoS locations.

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